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**Chen et al.**

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- (54) **REFLECTION CONVEX MIRROR STRUCTURE OF A VERTICAL LIGHT-EMITTING DIODE**
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**H01L 33/58** (2010.01)

(52) **U.S. Cl.**  
USPC ..... **257/98**; 257/72; 257/73

(58) **Field of Classification Search**  
USPC ..... 257/79, 98, E33.067, E33.068, 72, 257/73

See application file for complete search history.

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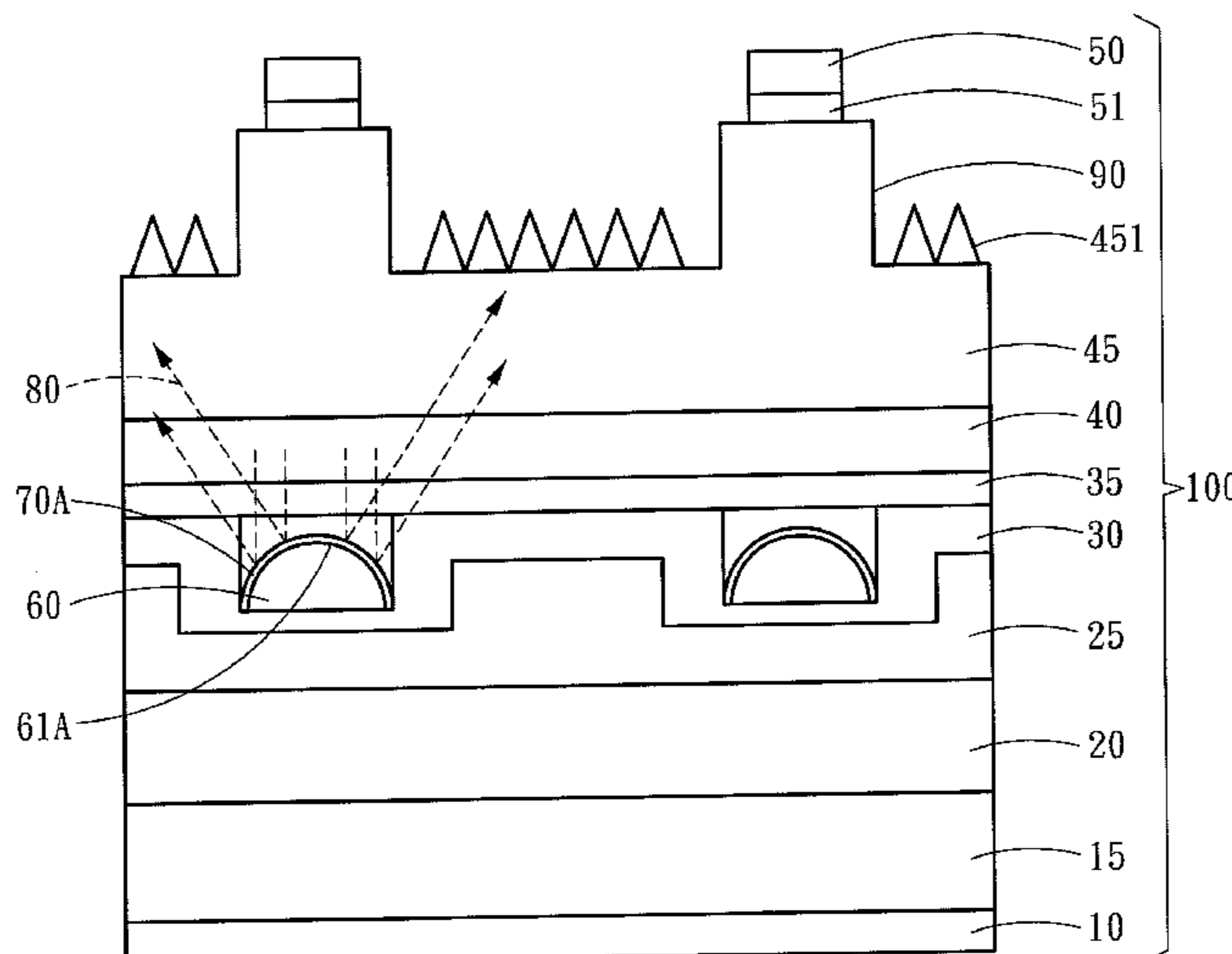
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(57) **ABSTRACT**

A reflection convex mirror structure is applied to a vertical light-emitting diode (LED) which comprises a P-type electrode, a permanent substrate, a binding layer, a buffer layer, a mirror layer, a P-type semiconductor layer, a light-emitting layer, an N-type semiconductor layer and an N-type electrode that are stacked in sequence. Between the P-type semiconductor layer and the mirror layer, a filler and a mirror are disposed right below the N-type electrode. The filler is made of a transparent material and has a convex surface facing the light-emitting layer. The mirror is formed on the convex surface of the filler. By utilizing the filler and the mirror to form the reflection convex mirror structure, excited light is reflected towards two sides, so that the excited light can dodge the N-type electrode without being shielded to increase light extraction efficiency.

**12 Claims, 9 Drawing Sheets**



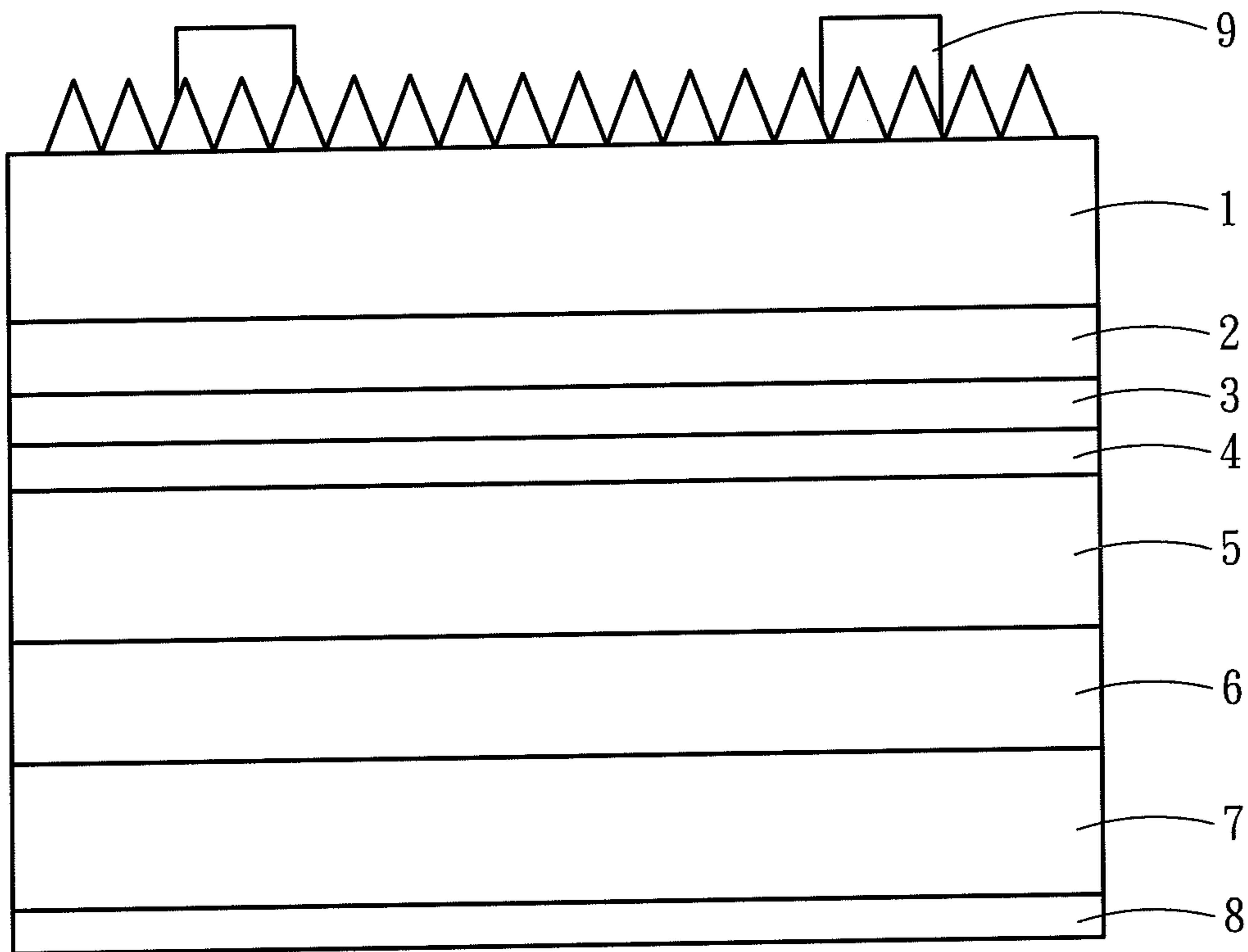


Fig . 1  
PRIOR ART

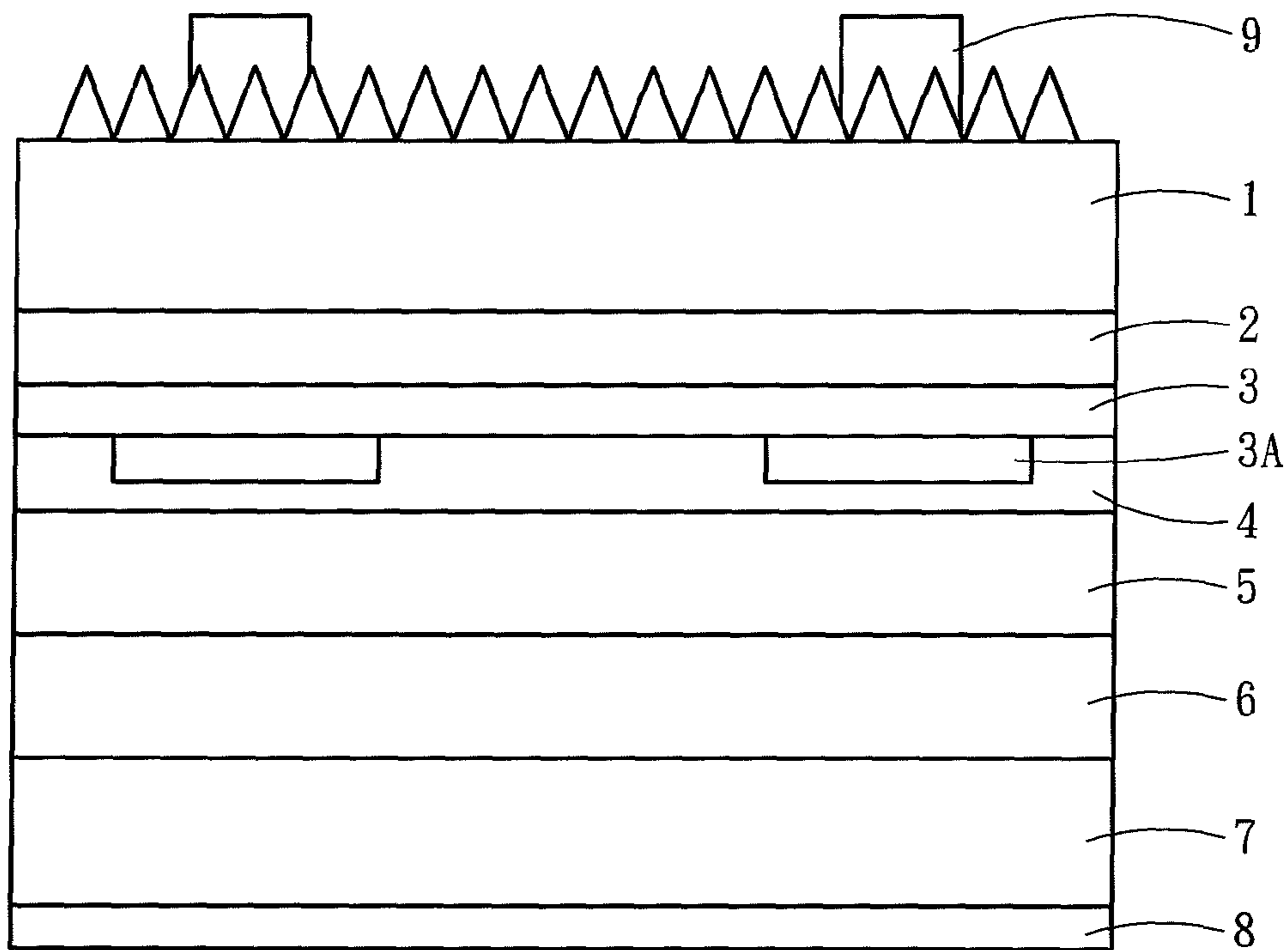


Fig . 2  
PRIOR ART

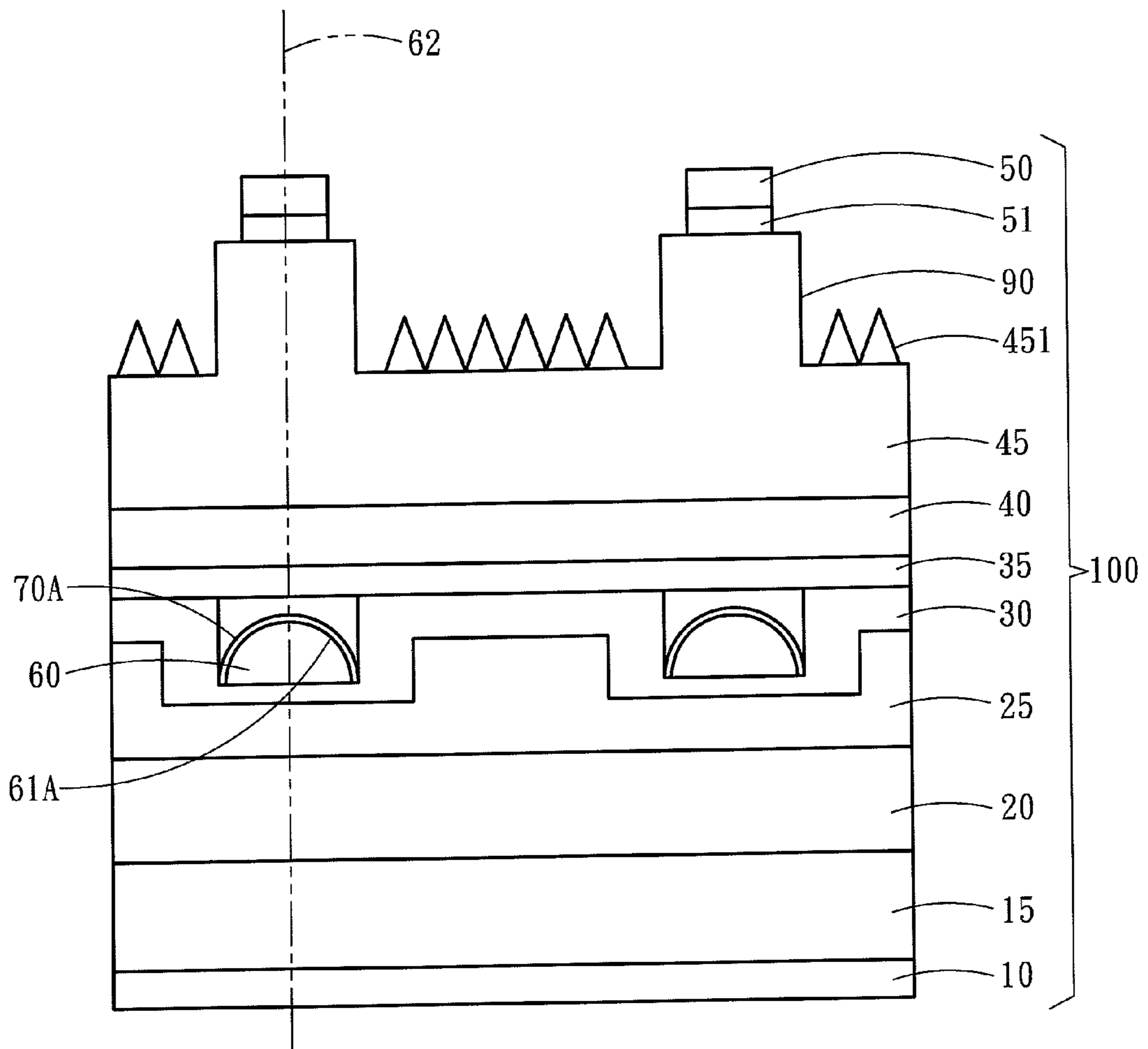


Fig . 3

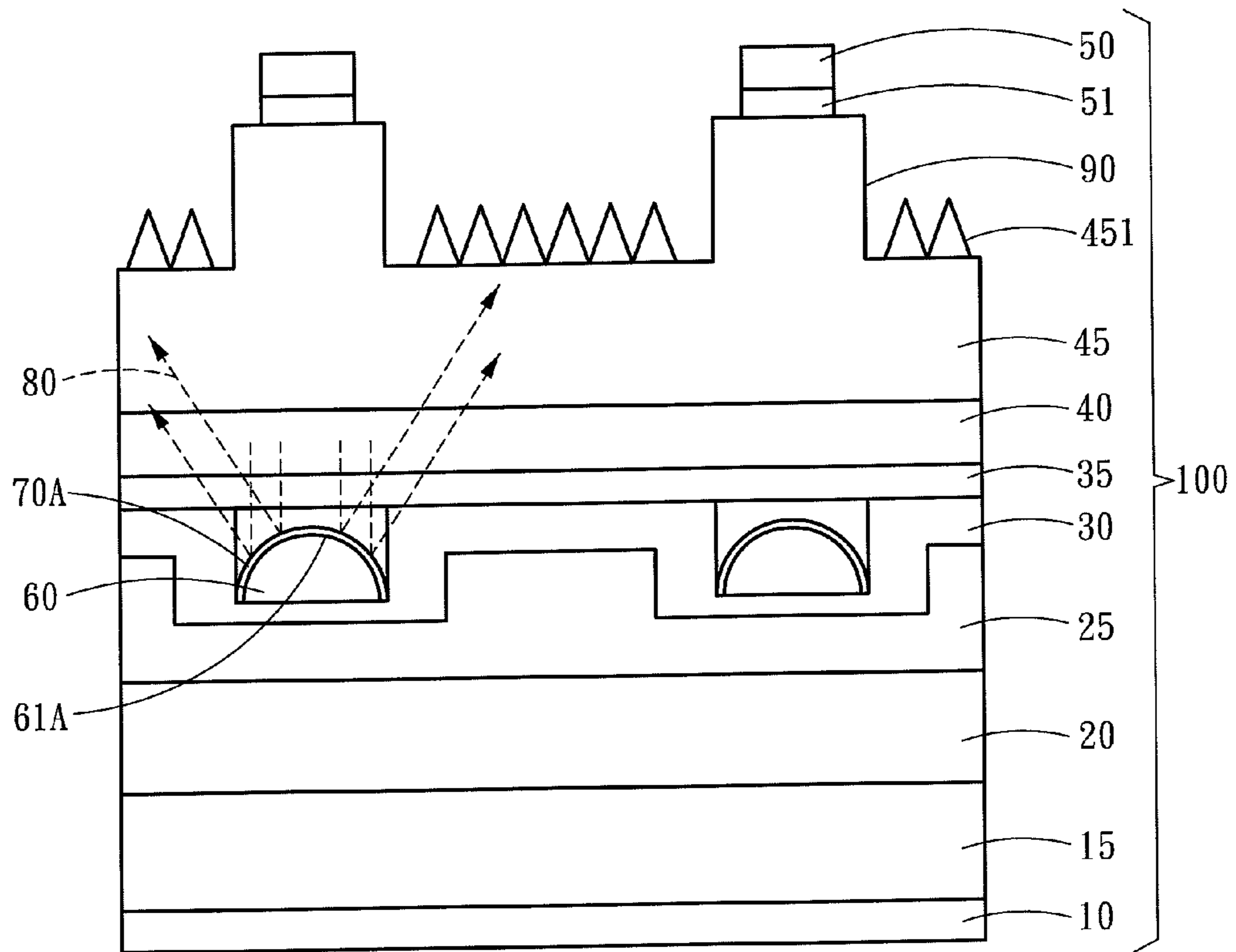


Fig . 4

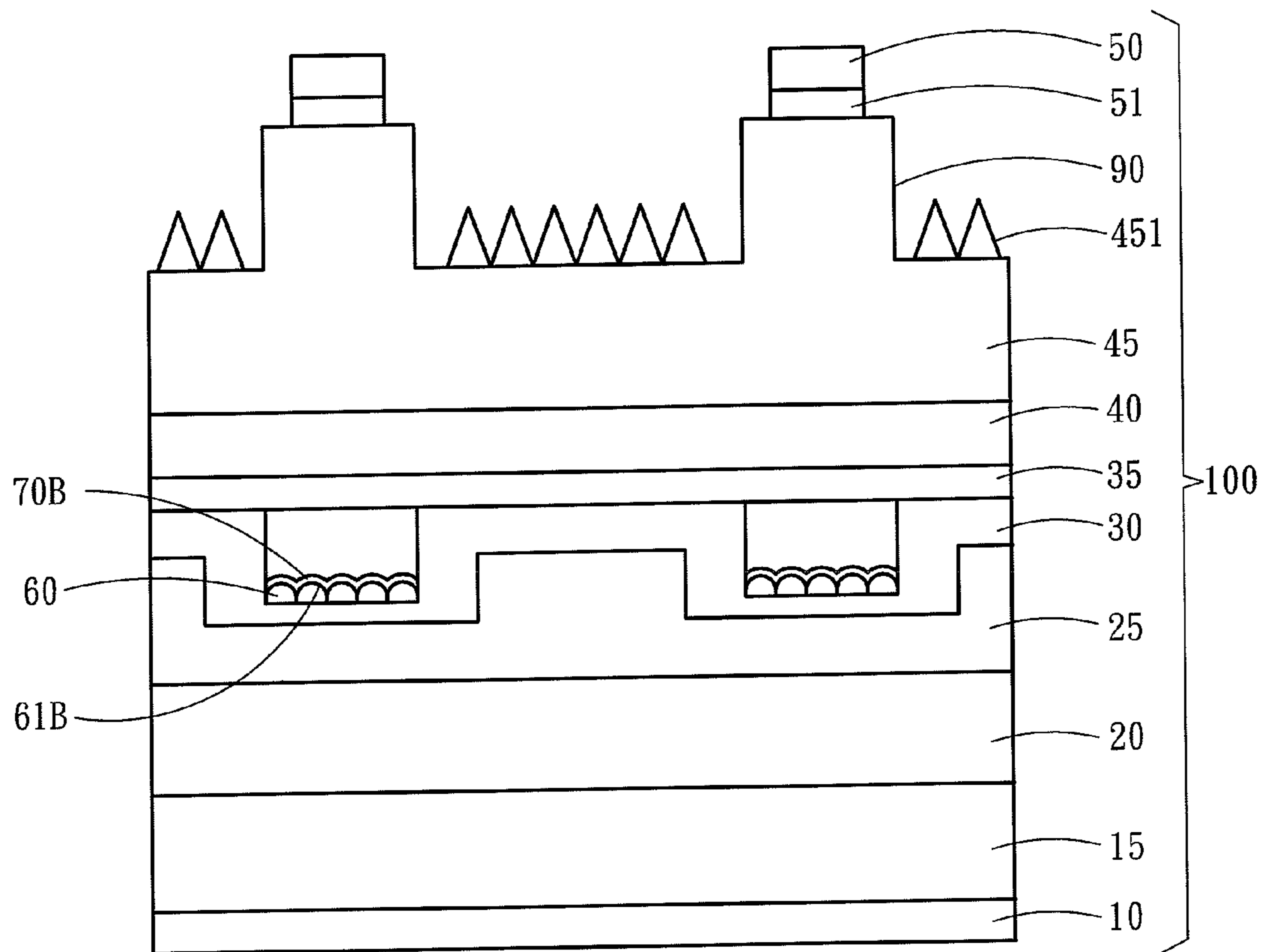


Fig . 5

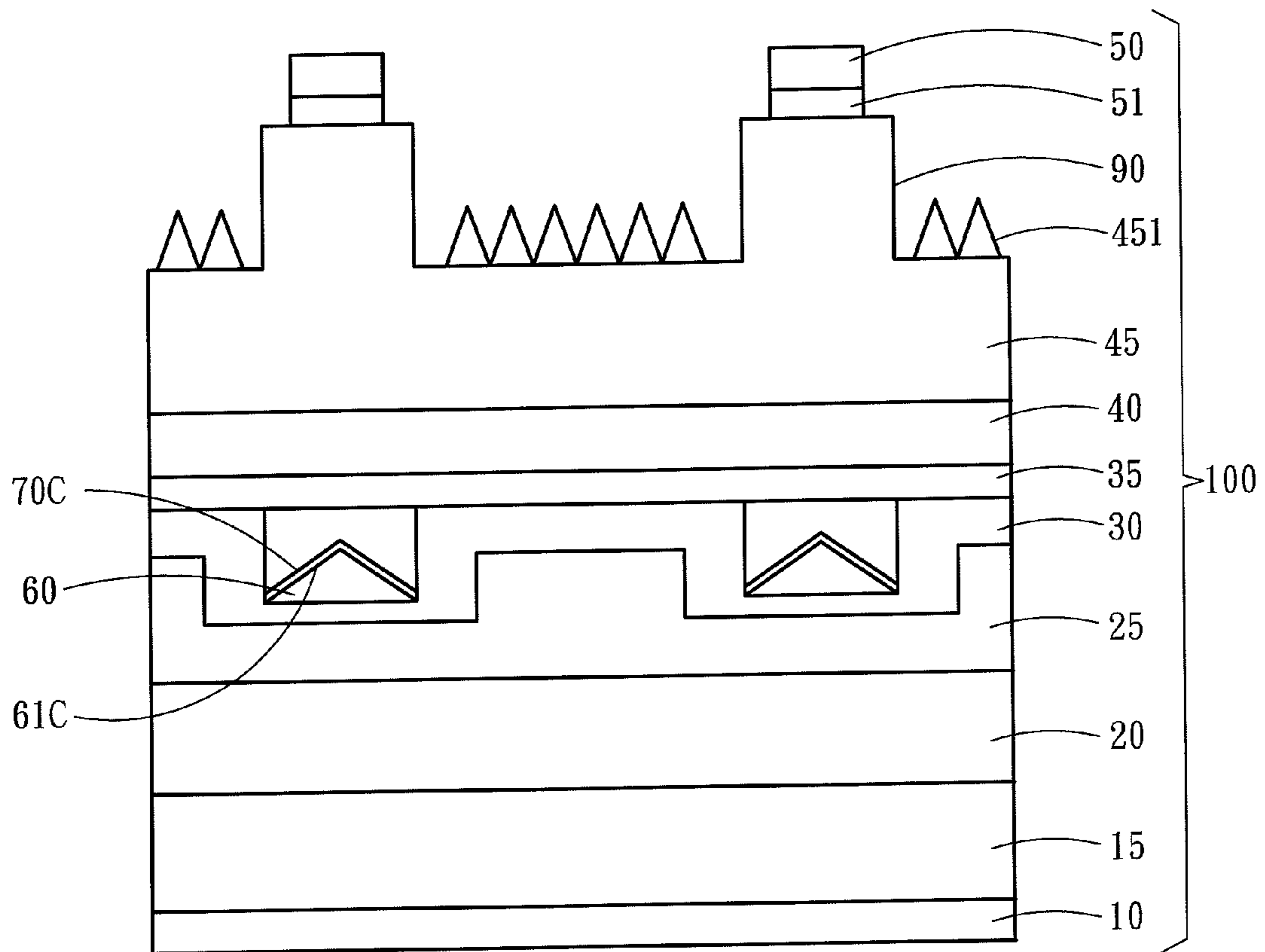


Fig . 6

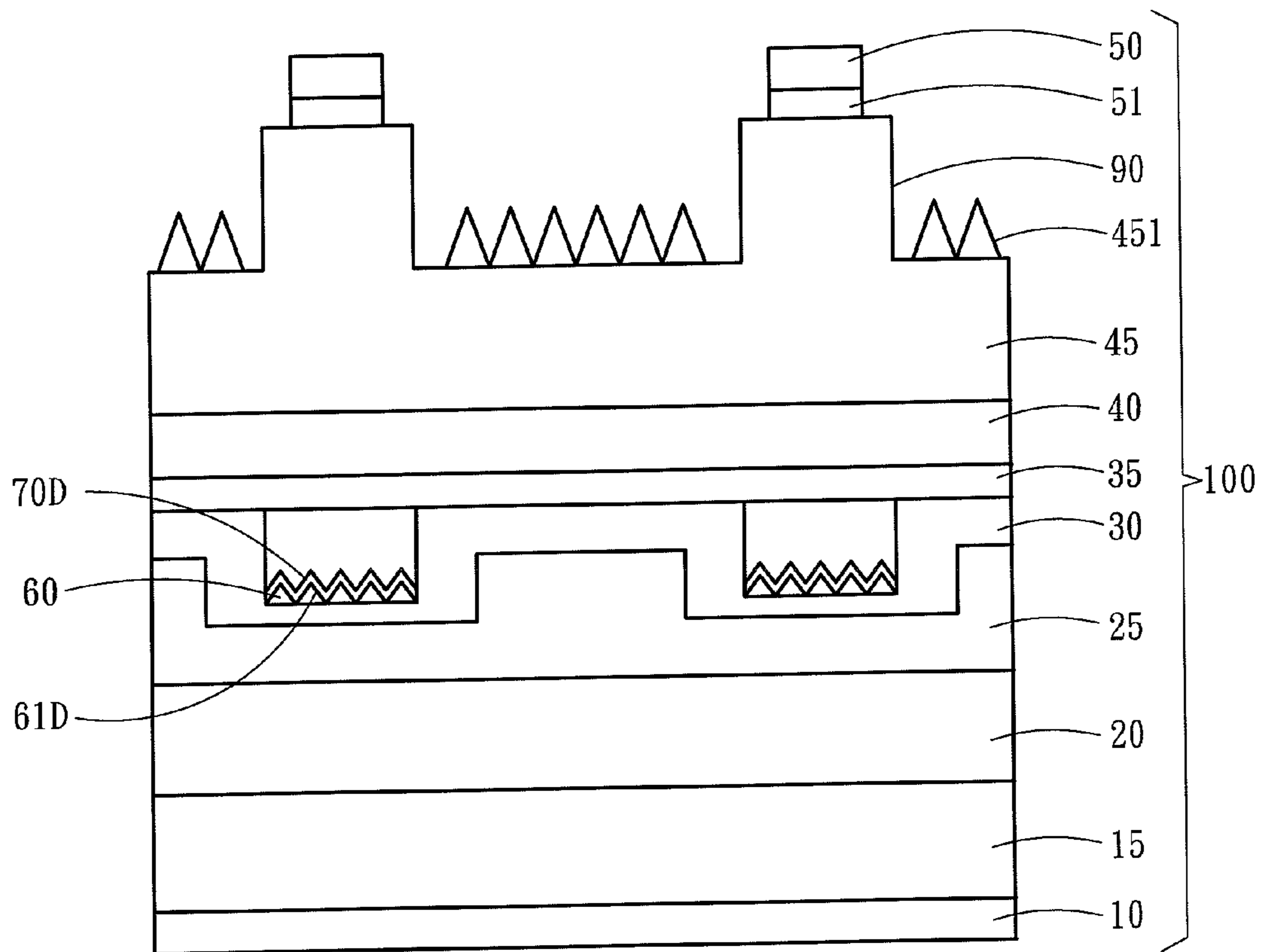


Fig . 7



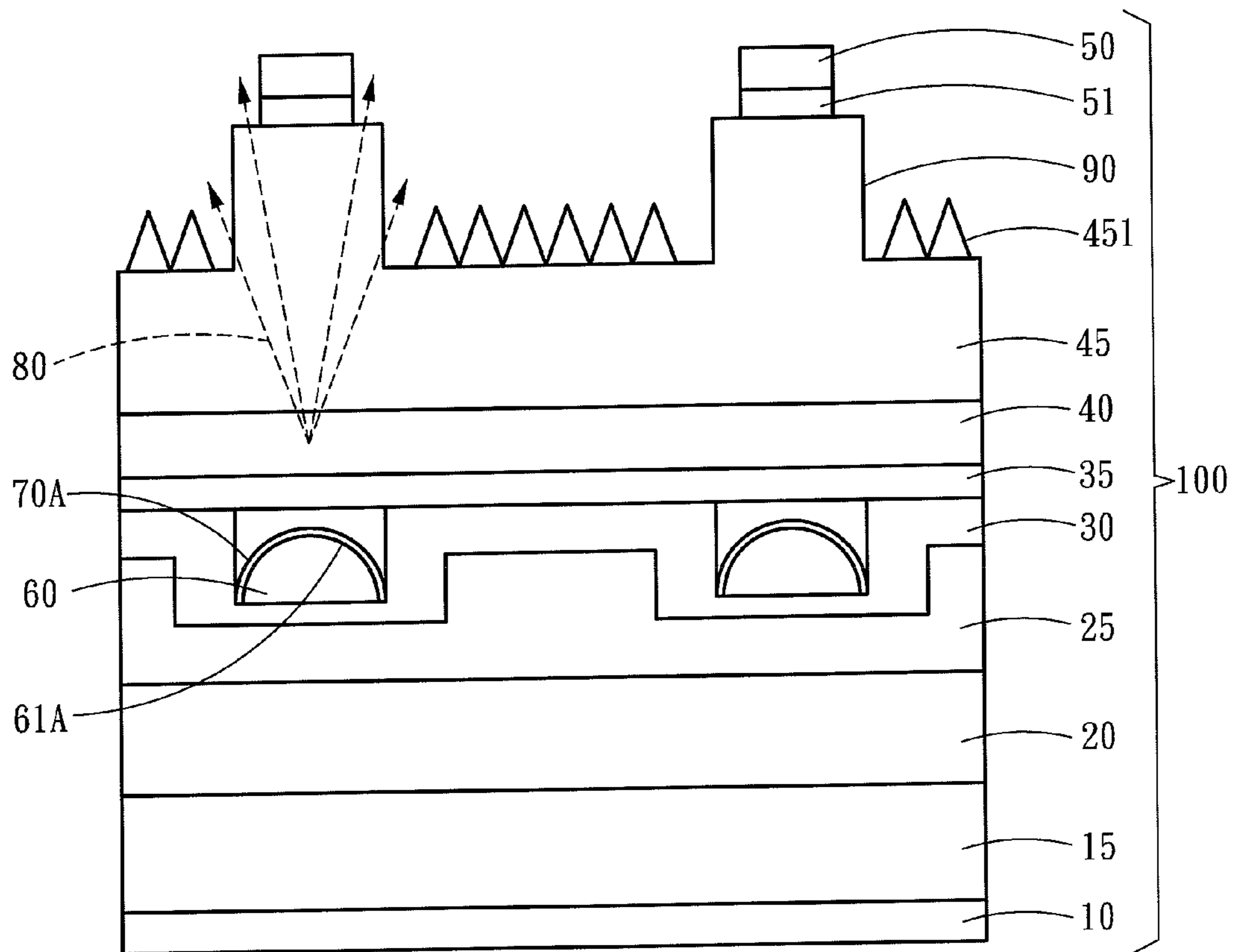


Fig . 8

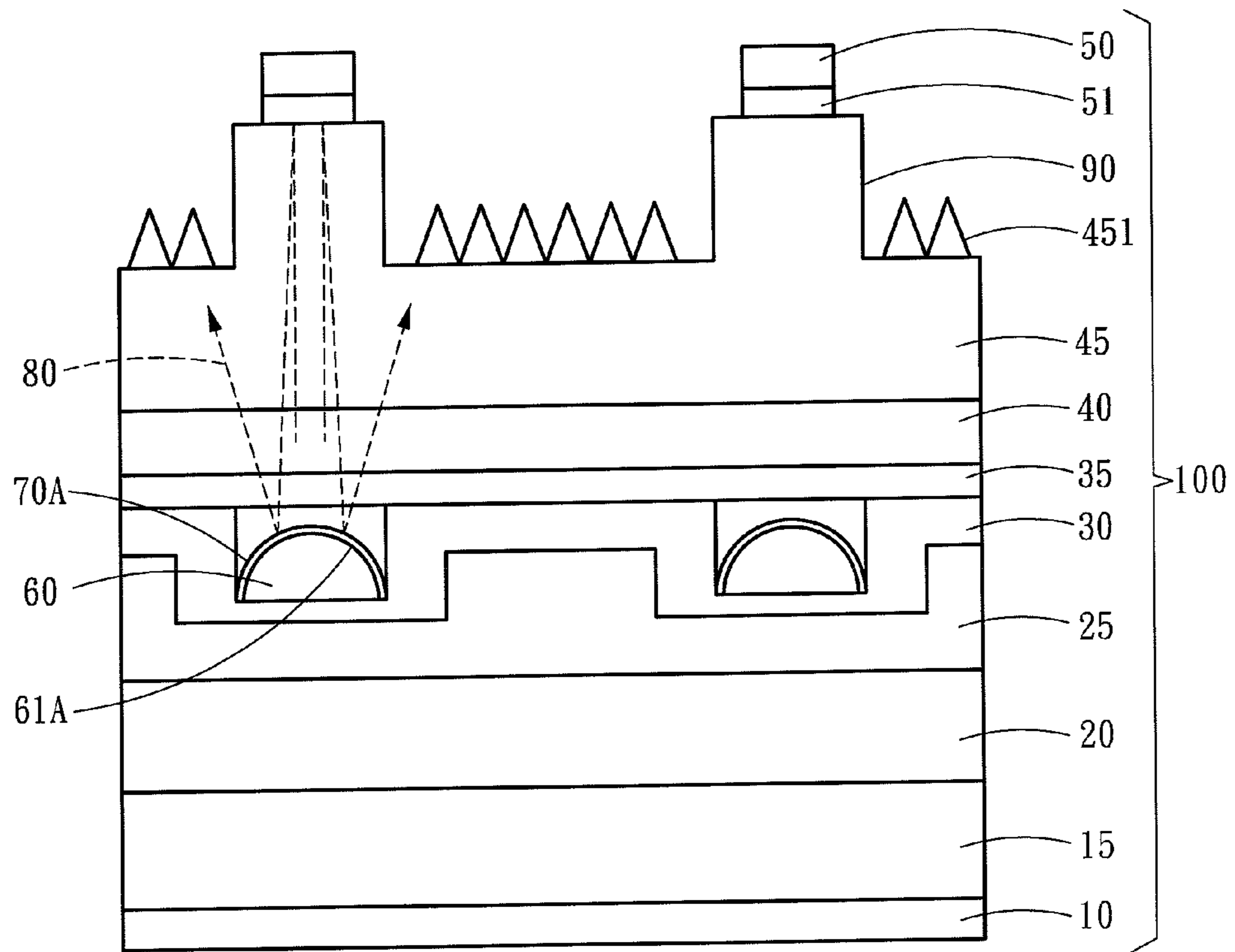


Fig . 9

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**REFLECTION CONVEX MIRROR  
STRUCTURE OF A VERTICAL  
LIGHT-EMITTING DIODE**

FIELD OF THE INVENTION

The present invention relates to a light-emitting diode (LED), and particularly to an LED structure capable of increasing light extraction efficiency.

BACKGROUND OF THE INVENTION

FIG. 1 shows a conventional vertical LED. The conventional vertical LED includes a sandwich structure formed by an N-type semiconductor layer 1, a light-emitting layer 2 and a P-type semiconductor layer 3. Below the P-type semiconductor layer 3, a mirror layer 4, a buffer layer 5, a binding layer 6, a silicon substrate 7 and a P-type electrode 8 are disposed in sequence. A surface of the N-type semiconductor layer 1 is processed by a roughening treatment for increasing an optical emission rate. An N-type electrode 9 is further disposed on the roughened surface of the N-type semiconductor layer 1.

By applying a voltage between the N-type electrode 9 and the P-type electrode 8, the N-type semiconductor layer 1 is enabled to provide electrons and the P-type semiconductor layer 3 is enabled to provide holes. Light is produced by the electrons and holes combining at the light-emitting layer 2 to further generate excited light through energy level jump.

Again referring to FIG. 1, a region right below the N-type electrode 9 has a highest current density, and so a main light-emitting region of the light-emitting layer 2 falls right below the N-type electrode 9. However, since the N-type electrode 9 is opaque and occupies 10% to 23% of an overall area of the LED, a substantial ratio of the excited light is shielded. More specifically, the loss of the excited light may reach as high as 15% to 38% due to the main light-emitting region right below the N-type electrode 9, such that light extraction efficiency suffers.

Referring to FIG. 2, to increase the light extraction efficiency, a current blocking layer 3A is often disposed between the P-type semiconductor layer 3 and the mirror layer 4. The current blocking layer 3A is disposed right below the N-type electrode 9, inferring to that a current can only reach the light-emitting layer 2 by first bypassing the current block layer 3A. Thus, the main light-emitting region of the light-emitting layer 2 is no longer situated right below the N-type electrode 9, so that the excited light shielded by the N-type electrode 9 is reduced to increase the light extraction efficiency.

However, the presence of the current block layer 3A leads to increased resistance that reduces light-emitting efficiency of the LED. Further, a transmission speed of a horizontal current is greater than that of a vertical current. When the current block layer 3A is utilized for guiding the current not to pass through the light-emitting layer 2 right below the N-type electrode 9, the light-emitting layer 2 right below the N-type electrode 9 still has considerable brightness due to the transmission of the horizontal current. As a result, a substantial amount of light remains being shielded by the N-type electrode 9 to lead 5% to 20% loss. In conclusion, the light extraction efficiency is limited and fails to fulfill actual requirements.

In another conventional approach for increasing the light extraction efficiency, a thickness of an epitaxy layer is enlarged or a doping concentration is increased to improve a current transmission capability. Through the high current

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transmission capability, the area of the N-type electrode 9 can be reduced to further decrease a shielded region. However, regardless whether the thickness of the epitaxy layer is enlarged or the doping concentration is increased, a quality of the epitaxy is severely degraded. Further, a current density gets larger as the current increases, such that problems of a boosted forward voltage and burning the electrode are likely incurred.

In yet another conventional approach for increasing the light extraction efficiency, a reflection metal is disposed right below the N-type electrode 9 to reflect the excited light shielded by the N-type electrode 9. It should be noted that, in a vertical LED, as previously stated, the mirror layer 4 is already disposed below the P-type semiconductor layer 3. When the reflection metal is disposed right below the N-type electrode, the excited light is incessantly reflected between the reflection metal and the mirror layer 4 till the excited light is fully depleted. Consequently, the excited light is still not extracted, namely the light extraction efficiency cannot be increased.

SUMMARY OF THE INVENTION

Therefore, the primary object of the present invention is to provide a structure capable of increasing light extraction efficiency by guiding a projection of excited light.

A reflection convex mirror structure of a vertical light-emitting diode (LED) is provided according to one embodiment of the present invention. The reflection convex mirror structure is applied to an LED structure which comprises a P-type electrode, a permanent substrate, a binding layer, a buffer layer, a mirror layer, a P-type semiconductor layer, a light-emitting layer, an N-type semiconductor layer and an N-type electrode that are stacked in sequence. Between the P-type semiconductor and the mirror layer, a filler and a mirror are disposed right below the N-type electrode. The filler is made of a transparent material and has a convex surface facing the light-emitting layer. The mirror is formed on the convex surface of the filler.

Thus, the reflection convex mirror structure of the present invention is formed by the filler and the mirror. When the excited light generated by the light-emitting layer located right below the N-type electrode is emitted downwards, the excited light is reflected by the reflection convex mirror structure towards two sides of the reflection convex mirror structure. That is to say, by means of the reflection convex mirror structure, the excited light generated by the light-emitting layer right below the N-type electrode can dodge the N-type electrode without being shielded, thereby increasing the light extraction efficiency.

The foregoing, as well as additional objects, features and advantages of the invention will be more readily apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a conventional LED.

FIG. 2 is a diagram of another LED.

FIG. 3 is a diagram of a structure according to one embodiment of the present invention.

FIG. 4 is a schematic diagram of light guide according to one embodiment of the present invention.

FIG. 5 is a diagram of a structure according to another embodiment of the present invention.

FIG. 6 is a diagram of a structure according to yet another embodiment of the present invention.

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FIG. 7 is a diagram of a structure according to yet another embodiment of the present invention.

FIG. 8 is a schematic diagram of light guide according to another embodiment of the present invention.

FIG. 9 is a schematic diagram of light guide according to yet another embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Details of the present invention shall be described with preferred embodiments below. It should be noted that, the embodiments are illustrative examples for explaining the present invention and are not to be construed as limiting the present invention.

Referring to FIG. 3, a reflection convex mirror structure of a vertical light-emitting diode (LED) is provided according to one embodiment of the present invention. The reflection convex mirror structure is applied to an LED structure 100 which comprises a P-type electrode 10, a permanent substrate 15, a binding layer 20, a buffer layer 25, a mirror layer 30, a P-type semiconductor layer 35, a light-emitting layer 40, an N-type semiconductor layer 45 and an N-type electrode 50 that are stacked in sequence. At a region without the N-type electrode 50, the N-type semiconductor layer 45 has an irregular surface 451. The irregular surface 451 is for preventing total reflection and increasing light extraction efficiency. For example, the irregular surface 451 is formed by a physical approach such as being formed by plasma impact or being formed by chemical etching.

Between the P-type semiconductor layer 35 and the mirror layer 30, a filler 60 and a mirror 70A are disposed right below the N-type electrode 50. The filler 60 is made of a transparent material and has a convex surface 61A. The convex surface 61A faces the light-emitting layer 40, and is formed by a semi-cylindrical structure, for example. The mirror 70A is formed on the convex surface 61A of the filler 60. The filler 60 further has a virtual symmetry line 62 aligning with a center of the N-type electrode 50.

Referring to FIG. 4, according to the above structure, when the light-emitting layer 40 generates excited light 80, the excited light 80 is vertically emitted downwards to the mirror 70A. Since the mirror 70A is adhered to the convex surface 61A to have the same convex shape as the convex surface 61A does, the excited light 80 can be reflected by the mirror 70A and projected towards two sides to dodge the N-type electrode 50, thereby increasing the light extraction efficiency.

Referring to FIGS. 5, 6 and 7, in other embodiments of the present invention, a convex surface 61B may also be formed by a plurality of semi-cylindrical structures that are arranged in a juxtaposition manner. Alternatively, a convex surface 61C may be formed by a triangular prism structure, or a convex surface 61D may be formed by a plurality of triangular prism structures that are arranged in a juxtaposition manner. Mirrors 70B, 70C and 70D have corresponding shapes to the respective convex surfaces 61B, 61C and 61D, and also can reflect the excited light 80 that projects downwards to the two sides.

Referring to FIG. 8, the N-type semiconductor layer 45 may have an elevated platform 90 corresponding to the N-type electrode 50. Preferably, the elevated platform 90 is formed at a height between 1  $\mu\text{m}$  and 3  $\mu\text{m}$ . The N-type electrode 50 is disposed on the elevated platform 90 in an elevated manner. As shown in FIG. 8, the amount of the excited light 80 shielded by the N-type electrode 50 is significantly reduced, thus increasing the light extraction efficiency.

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Referring to FIG. 9, in an alternative embodiment of the present invention, an electrode mirror layer 51 is provided between the N-type electrode 50 and the N-type semiconductor layer 45. As shown in FIG. 9, the electrode mirror layer 51 reflects the excited light 80 emitted upwards by the light-emitting layer 40. After being reflected, the excited light 80 is projected downwards to the mirror 70A, and is then reflected outwards by the mirror 70A without being shielded by the N-type electrode 50, thereby increasing the light extraction efficiency.

Further, for example, the filler 60 of the present invention may be made of a conductive material for reducing resistance and increasing the light extraction efficiency. Alternatively, the filler 60 may also be made of a transparent material selected from a group consisting of indium tin oxide (ITO), zinc gallium oxide (GZO), zinc oxide (ZnO), silicon dioxide ( $\text{SiO}_2$ ), titanium dioxide ( $\text{TiO}_2$ ) and silicon nitride (SiN). The mirror 70A may be selected from a group consisting of aluminum (Al), silver (Ag) and gold (Au) that all have high reflection rate and are commonly used as reflection materials.

Thus, the reflection convex mirror structure of the present invention is formed by the filler and the mirror. When the excited light generated by the light-emitting layer located right below the N-type electrode is emitted downwards, the excited light is reflected by the reflection convex mirror structure towards two sides. That is to say, by means of the reflection convex mirror structure, the excited light generated by the light-emitting layer right below the N-type electrode can dodge the N-type electrode without being shielded, thereby increasing the light extraction efficiency. Further, as the N-type electrode is elevated and the electrode mirror layer is disposed between the N-type electrode and the N-type semiconductor layer, the light extraction efficiency is further increased to achieve the object of providing increasing light extraction efficiency.

While the preferred embodiments of the invention have been set forth for the purpose of disclosure, modifications of the disclosed embodiments of the invention as well as other embodiments thereof may occur to those skilled in the art. Accordingly, the appended claims are intended to cover all embodiments which do not depart from the spirit and scope of the invention.

What is claimed is:

1. A reflection convex mirror structure of a vertical light-emitting diode (LED) which comprises a P-type electrode, a permanent substrate, a binding layer, a buffer layer, a mirror layer, a P-type semiconductor layer, a light-emitting layer, an N-type semiconductor layer and an N-type electrode that are stacked in sequence, the reflection convex mirror structure being characterized in that:

the P-type semiconductor and the mirror layer are interposed by a filler and a mirror that are disposed right below the N-type electrode, the filler is made of a transparent material and includes a convex surface facing the light-emitting layer, and the mirror is formed on the convex surface of the filler.

2. The reflection convex mirror structure of claim 1, wherein the filler further includes a symmetry line aligning with a center of the N-type electrode.

3. The reflection convex mirror structure of claim 1, wherein the convex surface is formed by a semi-cylindrical structure.

4. The reflection convex mirror structure of claim 1, wherein the convex surface is formed by a plurality of semi-cylindrical structures that are arranged in a juxtaposition manner.

5. The reflection convex mirror structure of claim 1, wherein the convex surface is formed by a triangular prism structure.

6. The reflection convex mirror structure of claim 1, wherein the convex surface is formed by a plurality of triangular prism structures that are arranged in a juxtaposition manner.

7. The reflection convex mirror structure of claim 1, wherein the N-type semiconductor layer includes an elevated platform corresponding to the N-type electrode, and the N-type electrode is disposed on the elevated platform.

8. The reflection convex mirror structure of claim 7, wherein the elevated platform is formed at a height between 1  $\mu\text{m}$  and 3  $\mu\text{m}$ .

9. The reflection convex mirror structure of claim 1, wherein the N-type electrode and the N-type semiconductor layer are interposed by an electrode mirror layer.

10. The reflection convex mirror structure of claim 1, wherein the transparent material is selected from a group consisting of indium tin oxide (ITO), zinc gallium oxide (GZO), zinc oxide (ZnO), silicon dioxide ( $\text{SiO}_2$ ), titanium dioxide ( $\text{TiO}_2$ ) and silicon nitride (SiN).

11. The reflection convex mirror structure of claim 1, wherein the mirror is made of a material selected from a group consisting of aluminum (Al), silver (Ag) and gold (Au).

12. The reflection convex mirror structure of claim 1, wherein the N-type semiconductor layer includes an irregular surface where no N-type electrode is formed.

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